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14. ABSTRACT
This presentation describes two methods for imaging an absorber used as a new sensor in determining the location of the focal spot for a solar concentrator. The absorber is used as a sensor in both methods, but in slightly different ways. The first method developed is an optimization method inspired by Shack-Hartmann wave front sensing. This optimization utilizes masking and a correlation calculation to determine the error from the current image of the focal spot and the ideal or designed position of the focal spot. The second method still uses the absorber as a sensor but calculates area moments of the reflected sunlight on the tubing to calculate the current location of the focal spot.

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COMPUTER PROGRAMS FOR SOLAR CONCENTRATOR FOCUS CONTROL

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5 Dec 2005

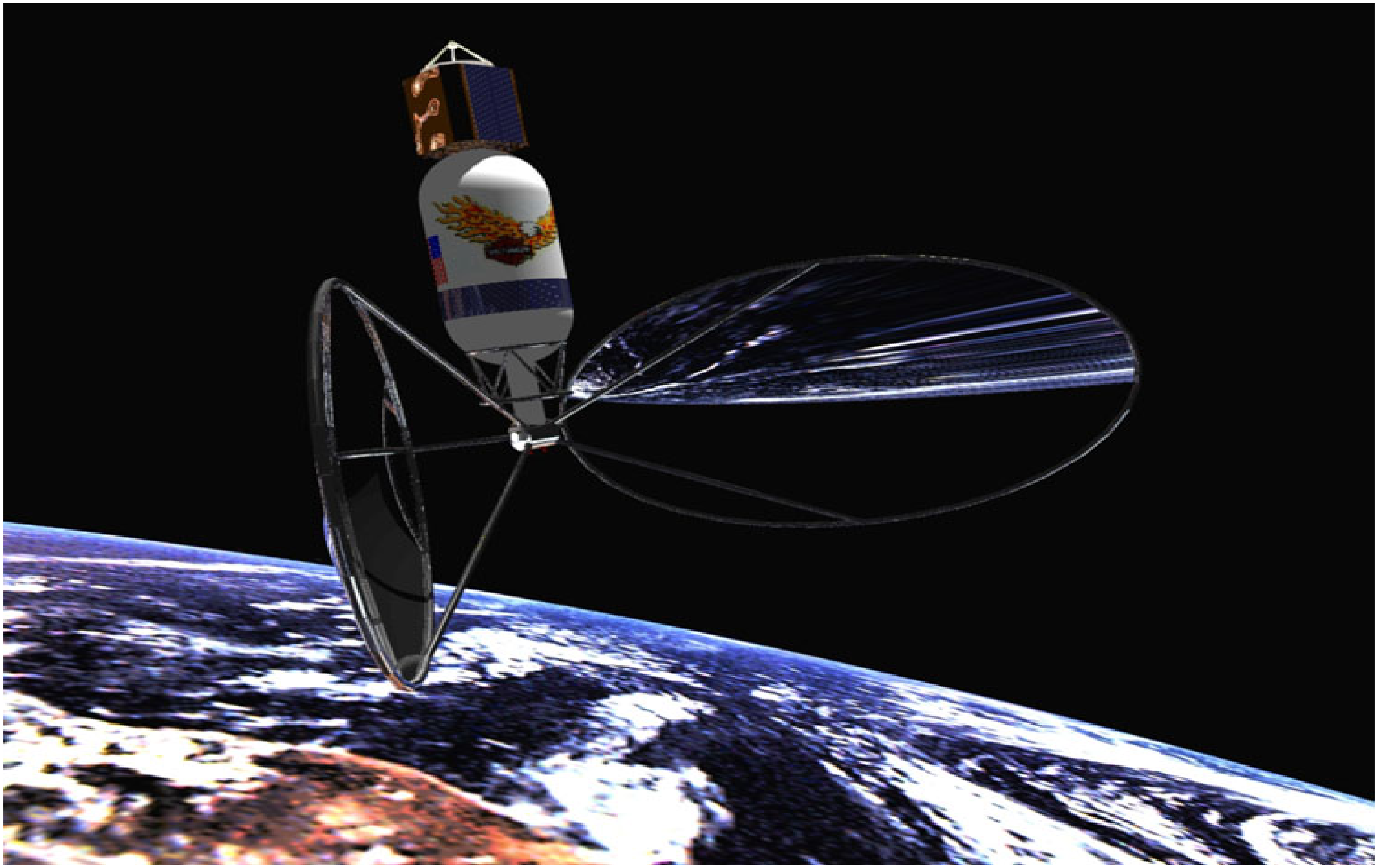
Agenda

- Introduction
- Problem Discussion
- Algorithm Introduction
- Experiment Description
- Results
- Conclusions and Future Work

Introduction

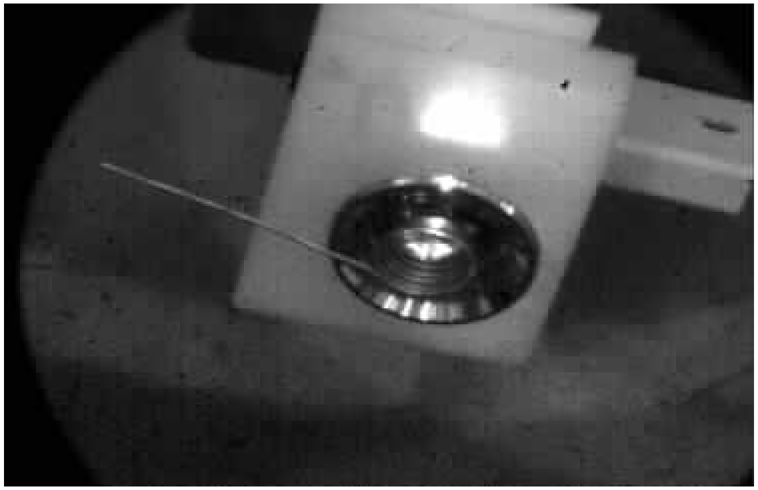
- **The major problem encountered when using a solar propulsion system is the proper placement of the focal spot on the thruster absorber plane. Without proper placement of the focal spot, solar energy is not transferred to the propellant gas.**

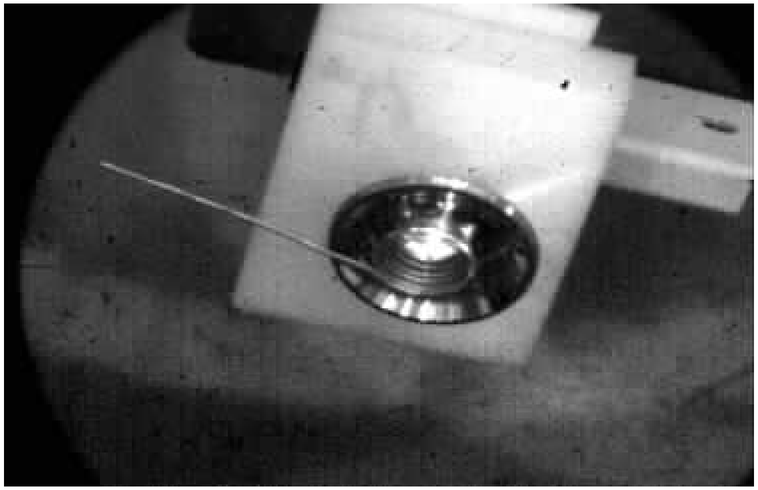
Solar Thermal Spacecraft Configuration



Problem

Determine location of solar focal spot on a visually complex thruster absorber and secondary concentrator. Visual complexity is compounded by specular reflection from the secondary concentrator and by the fact that the camera is moving with the concentrator.





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Basic Problem Solution Concept

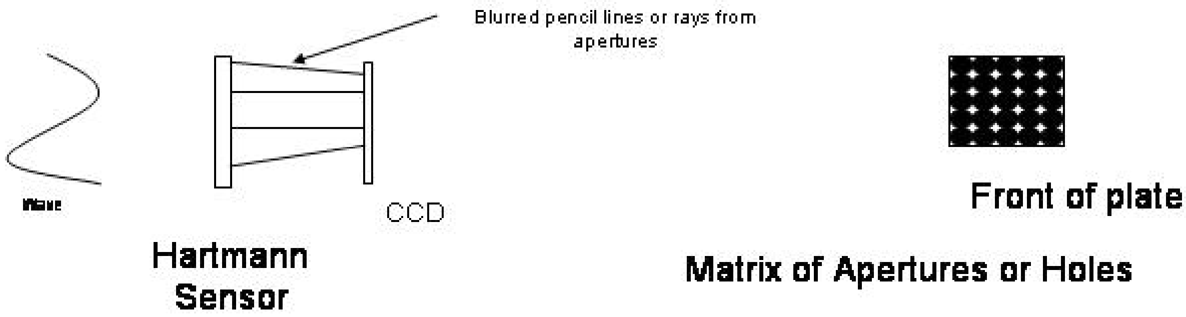
- **Use Charge Coupled Device (CCD) Camera as the primary fine focus sensor. Images of the thruster absorber are taken by the camera to be analyzed.**

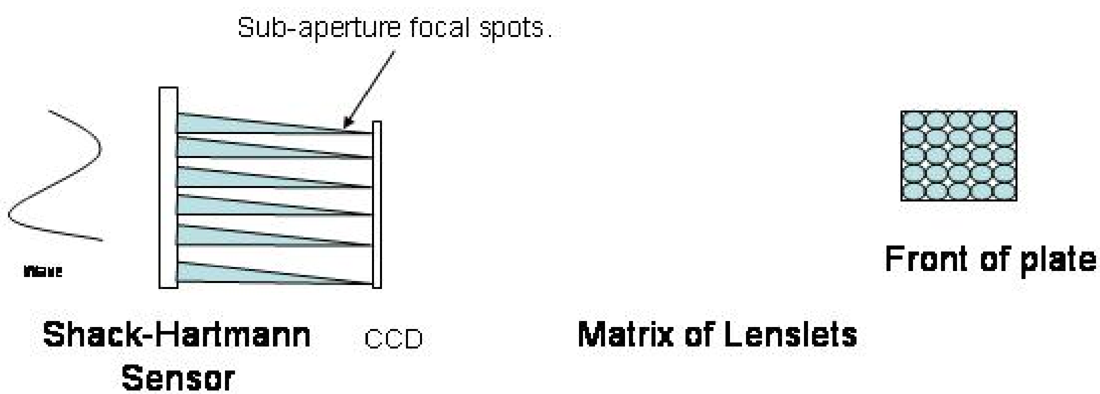
- **Develop algorithm(s) for determining focal spot position from image of thruster absorber and secondary concentrator to produce control commands for the main concentrator. Optimize control with respect to power or energy (temperature) transferred to the propellant gas.**

Wave Front Sensing

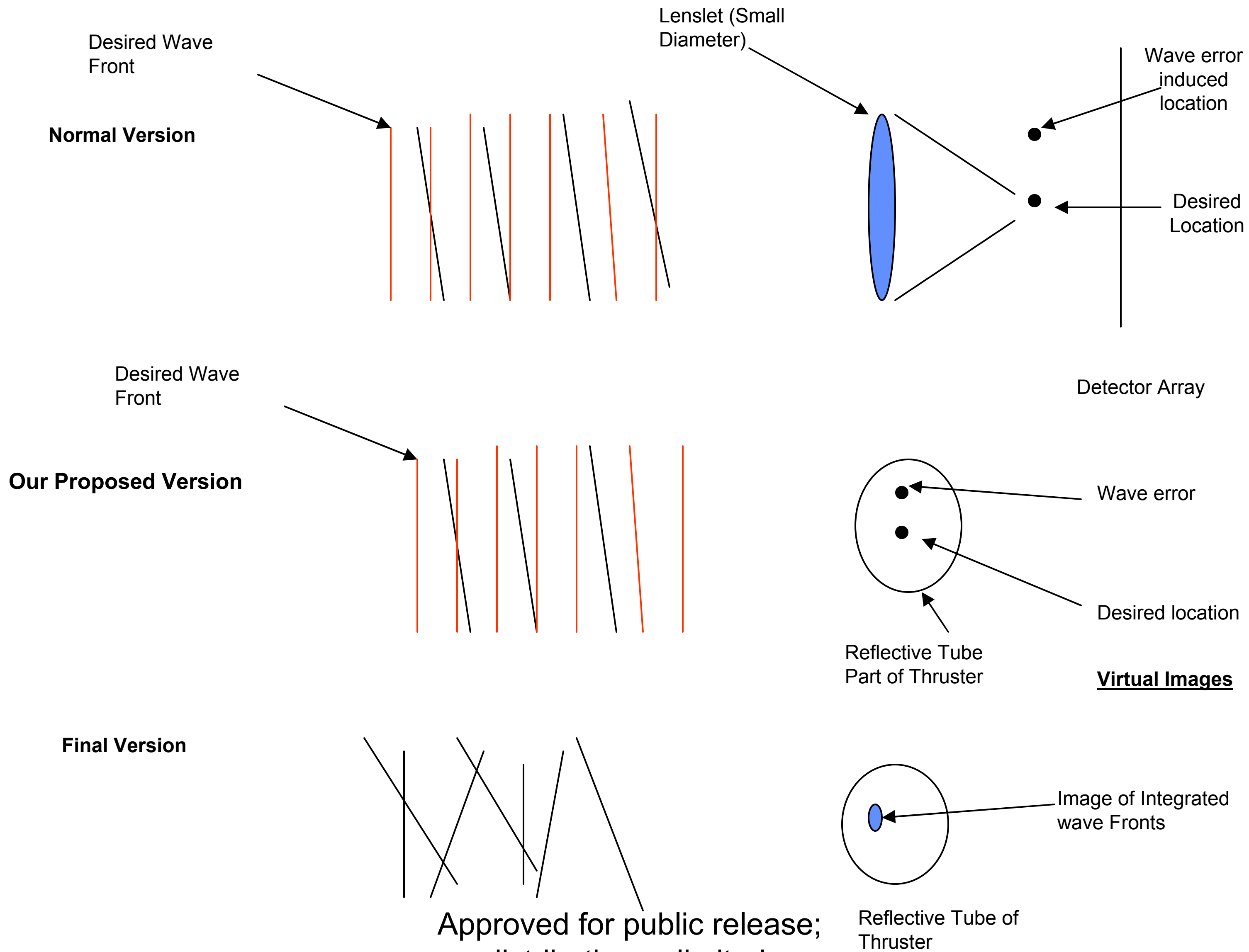
- **Hartmann Sensor**
  - **Utilized an array of holes or apertures to measure differences in tilt angle of waves by measuring the differences in position of the images of the apertures with a tilted waveform versus the images of the apertures with a non-tilted waveform. A lens behind the aperture plate collects the information and directs that information to a collector array.**
- **Shack-Hartmann Sensor**
  - **Replaced the array of apertures with small lenses or lenslets.**

Comparison of Wave Front Sensors





Wave Front Sensing(Cont.)



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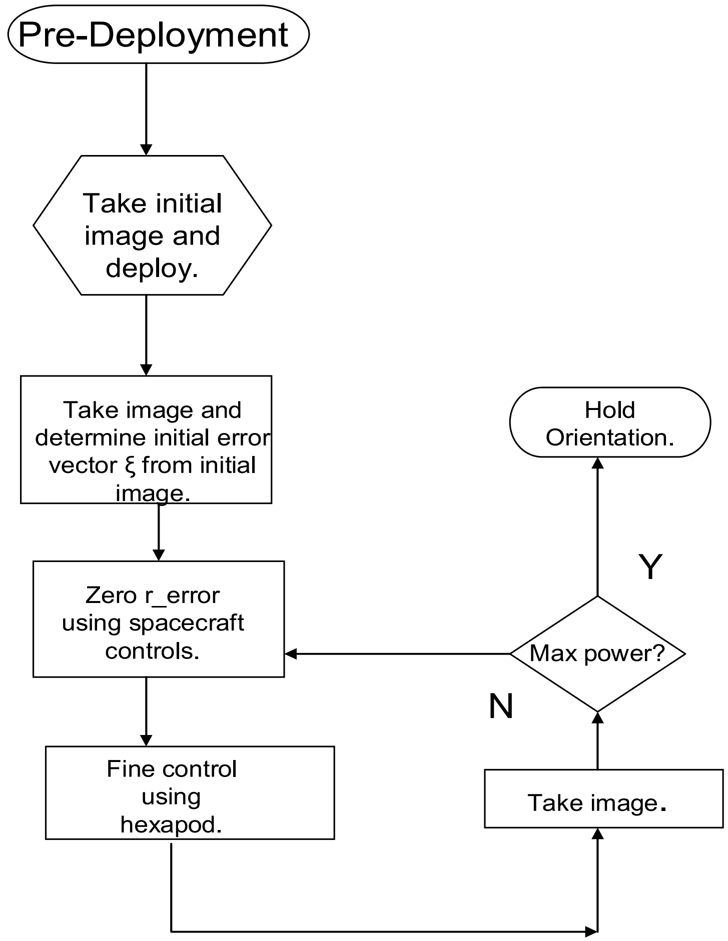
Algorithms

- **Method 1: A method that utilizes masking, correlation, and an optimization process to determine the position of the focus.**
- **Method 2: Utilizing area moments of the light reflected in each tube of the sensor, a centroid of light is determined and compared to the center of the sensor. The difference between the center position and the calculated centroid determines the direction to move the light to reduce that difference.**
- **By knowing where the center of the absorber is located with respect to the camera (a non-trivial assumption as the camera would probably be mounted on one of the concentrator's movable struts) , the computer should be able to generate x, y, z, roll, pitch, and yaw commands for the hexapod controller to move the concentrator to a new position to provide better focus and thus better heating.**

Flow Chart Of Methods



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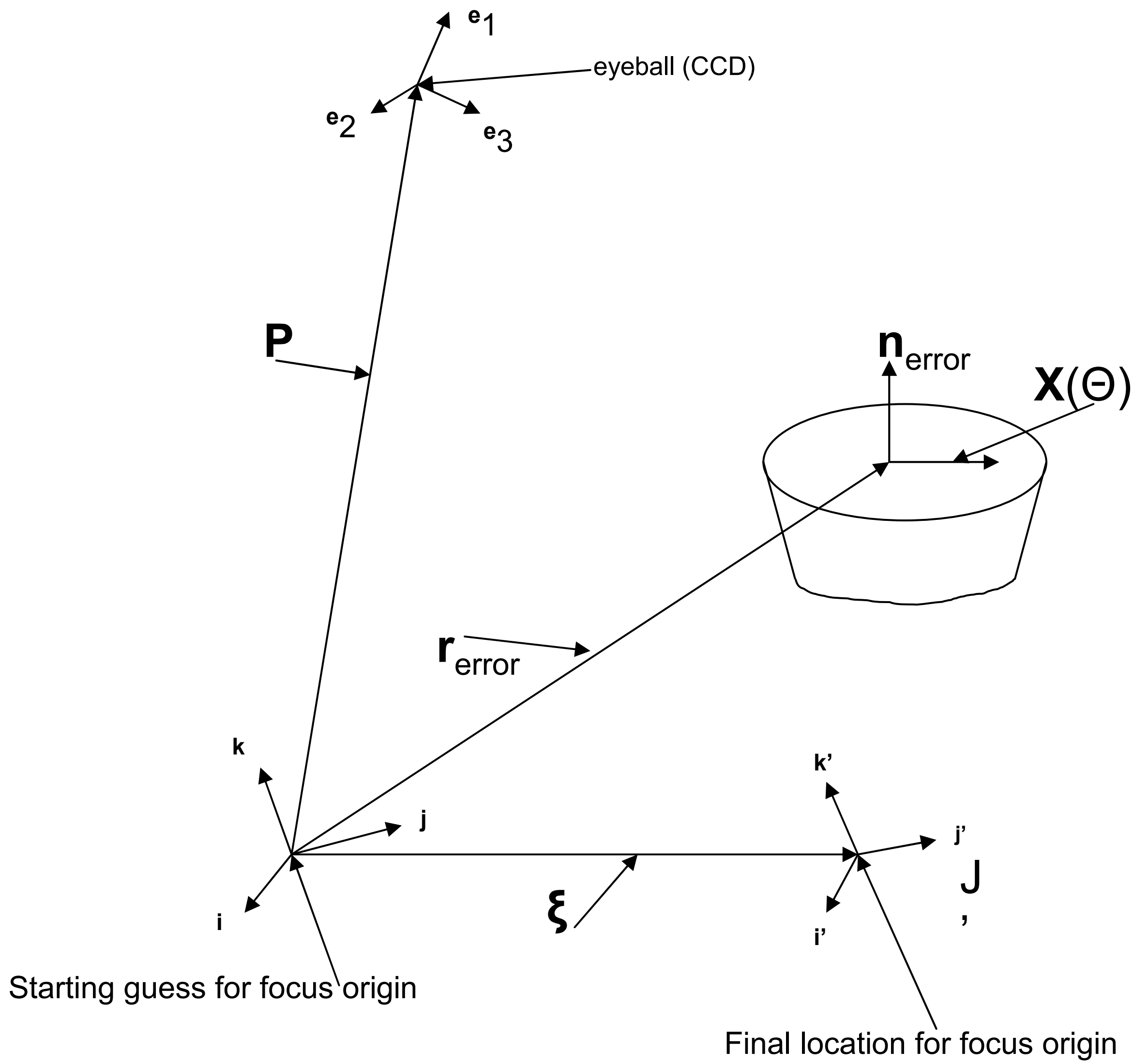
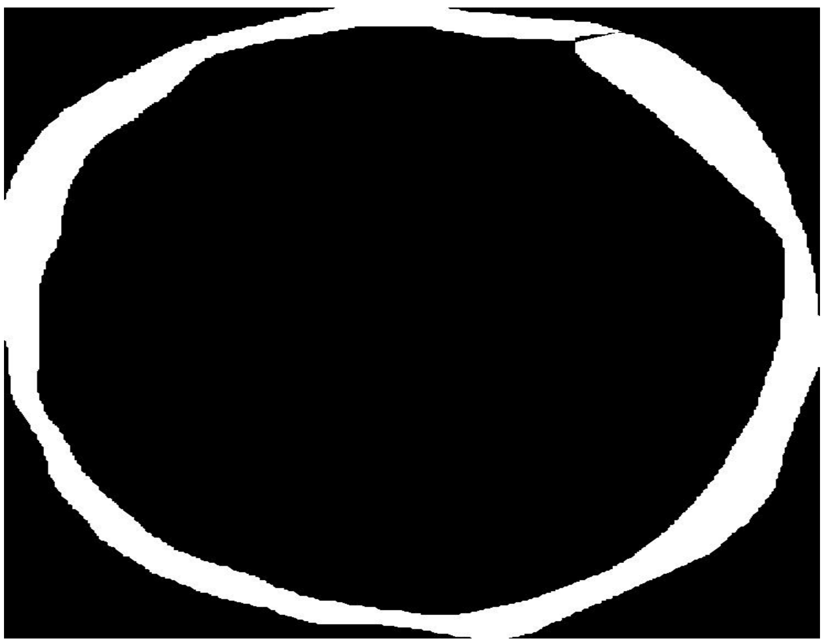
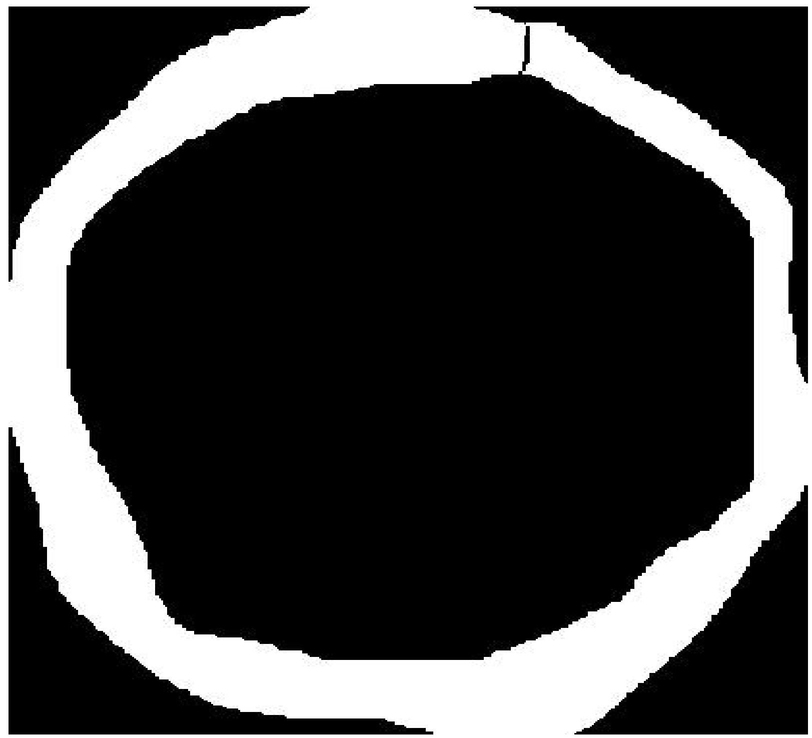
Starting Coordinates Method 1



Masks Used For Method 1



Outer Ring Mask



Inner Ring Mask

Method 1 Masks Continued

Banana Shape Mask

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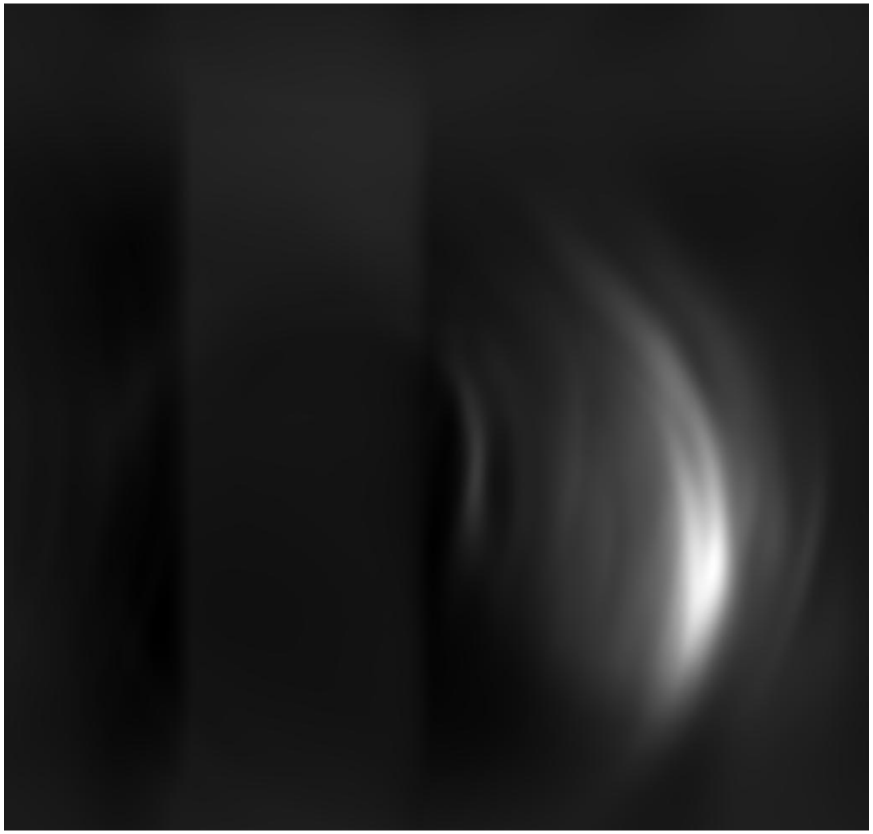
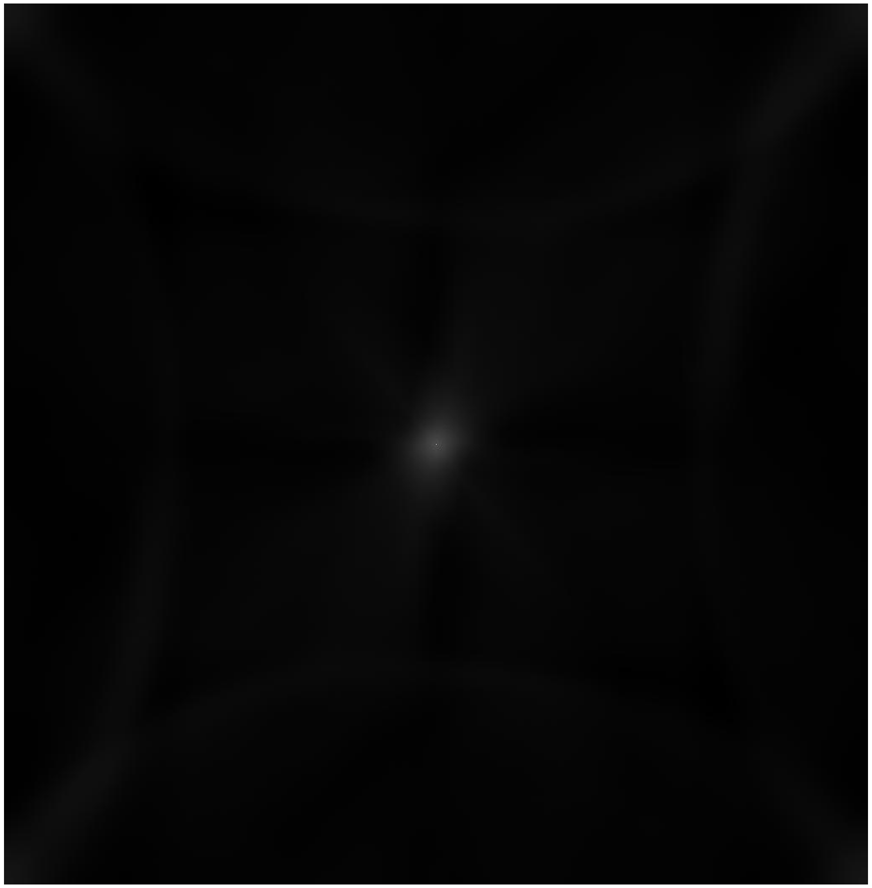
Correlation Results Method 1

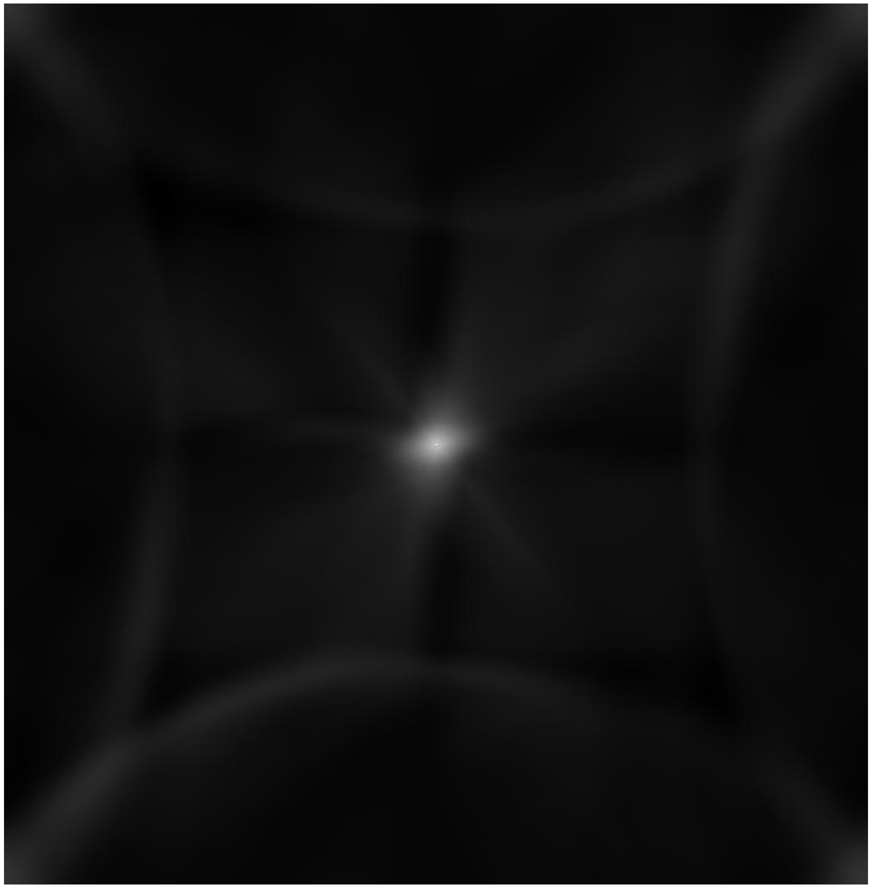


Correlation 4 Diam. Correlation. 2 Diam

Correlation Results

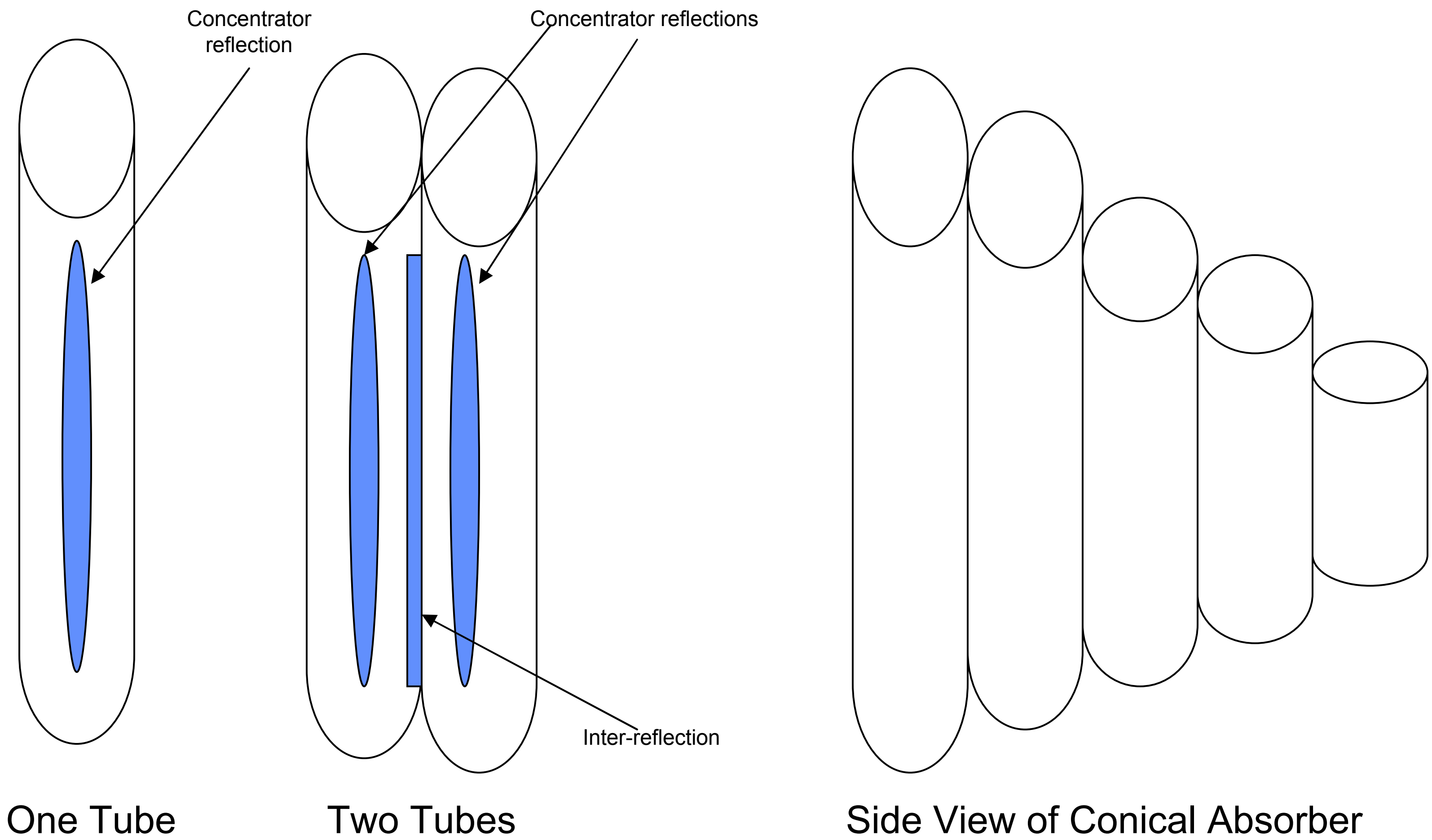


Autocorrelation



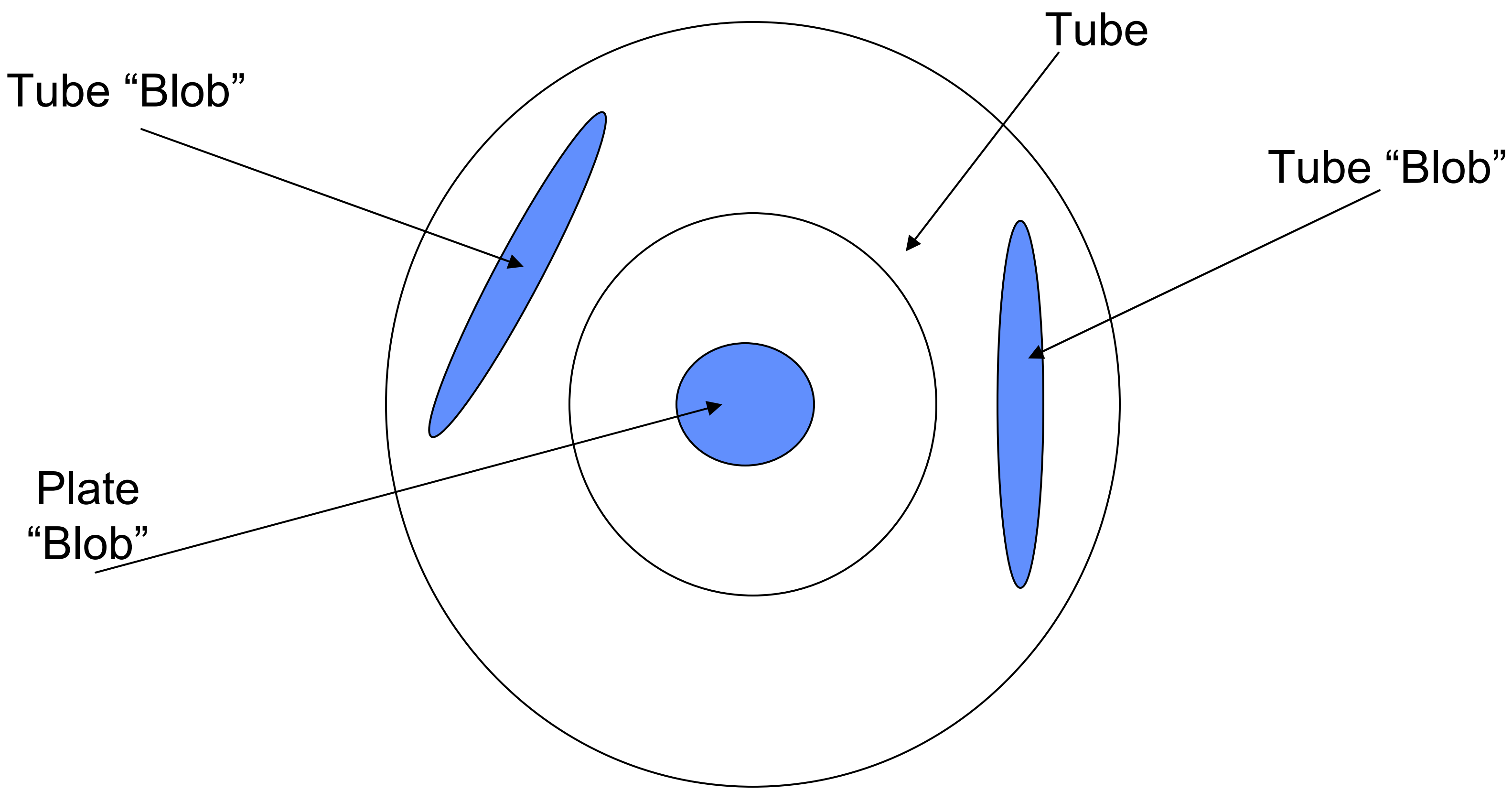
Correlation Up 1Diam

Cylindrical Mirror and Conical Absorber



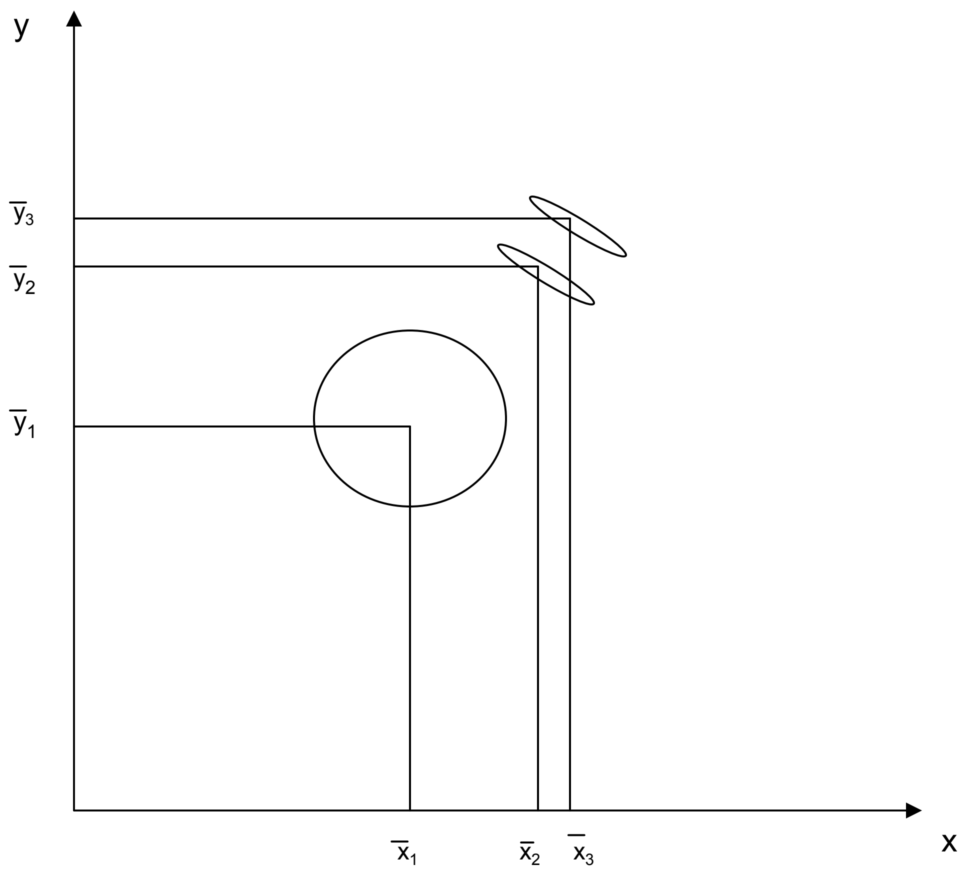
“Cylindrical Mirror”

Typical Image

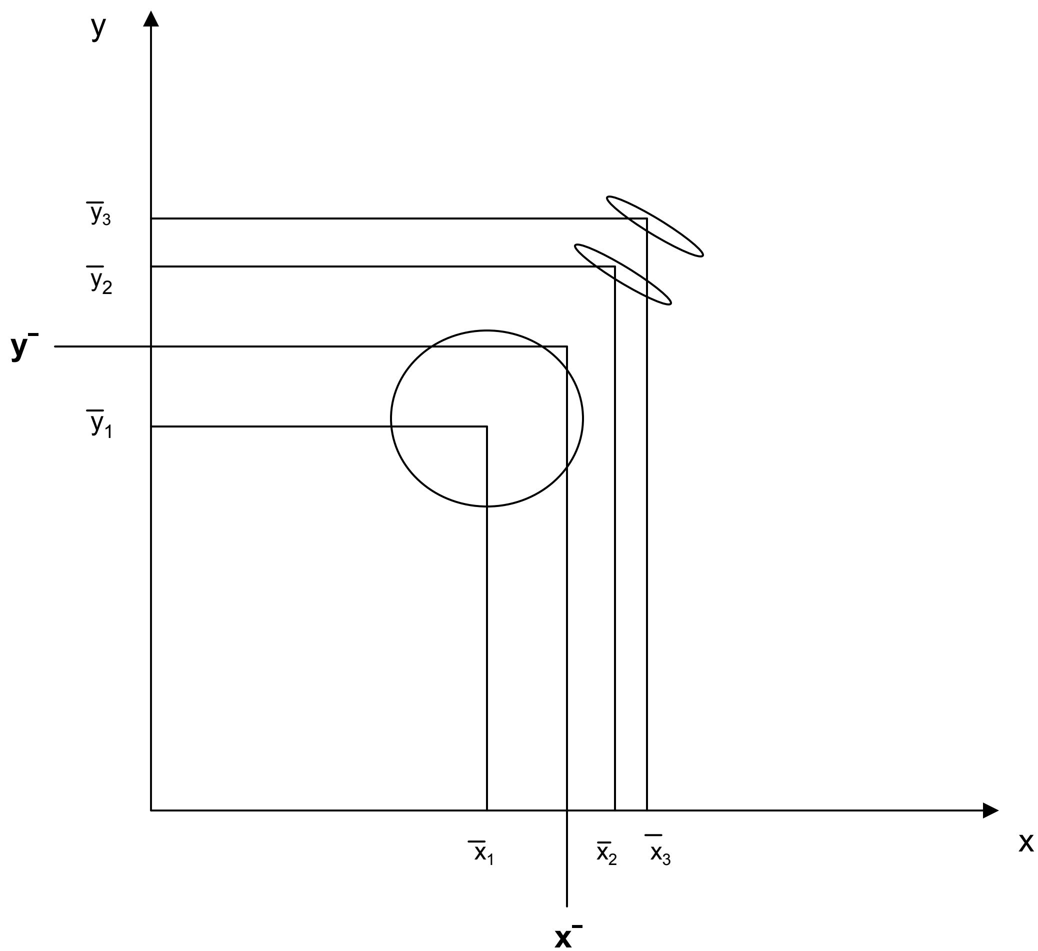


Tube “Blobs” can appear anywhere along or on the tube.
Plate “Blobs” appear on the plate in the center of the tube.

Area Centroids Determination



Centroid Construction Method 2



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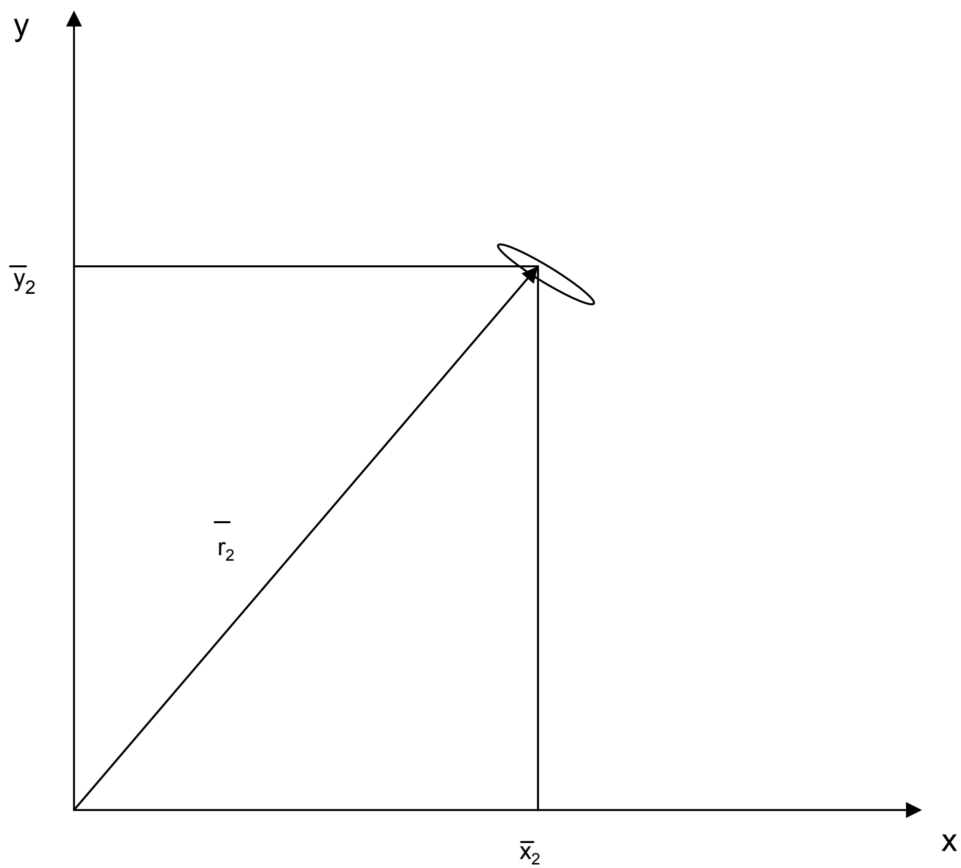
Angle Construction Area Moments



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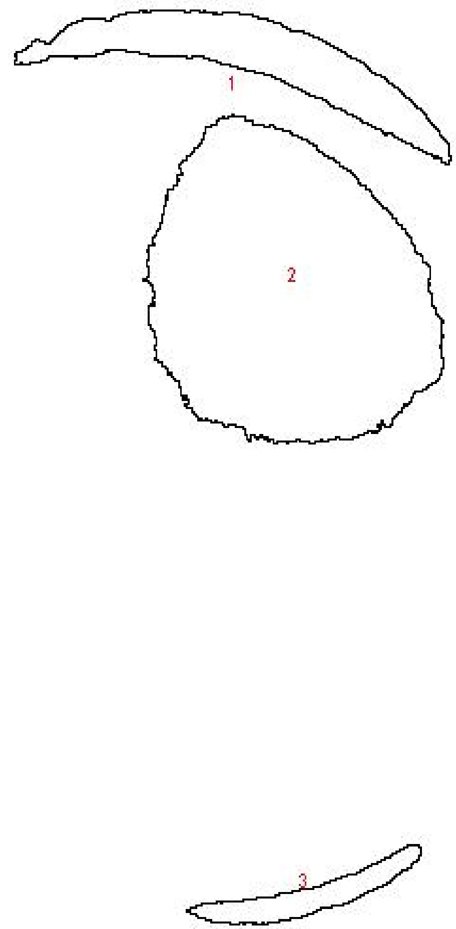
Blob Determination

On Focus Image



Blobs Count

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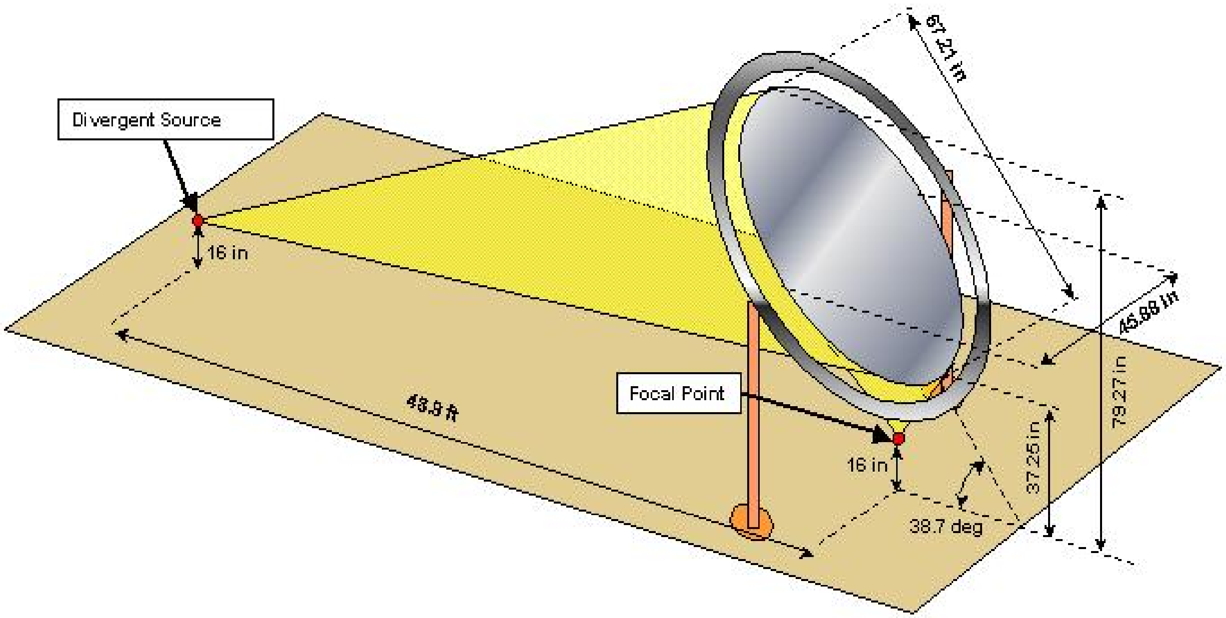
Experiment Setup

- **Utilize Stainless Steel Absorber to determine feasibility of methods.**
- **CCD Camera used to take images using SBIG Software CCDOPS.**
- **IMAGEJ GUI used to process images using both algorithms.**
- **3 inch LED light utilized to simulate the sun as an extended source.**

Experiment Schematic

Test Apparatus



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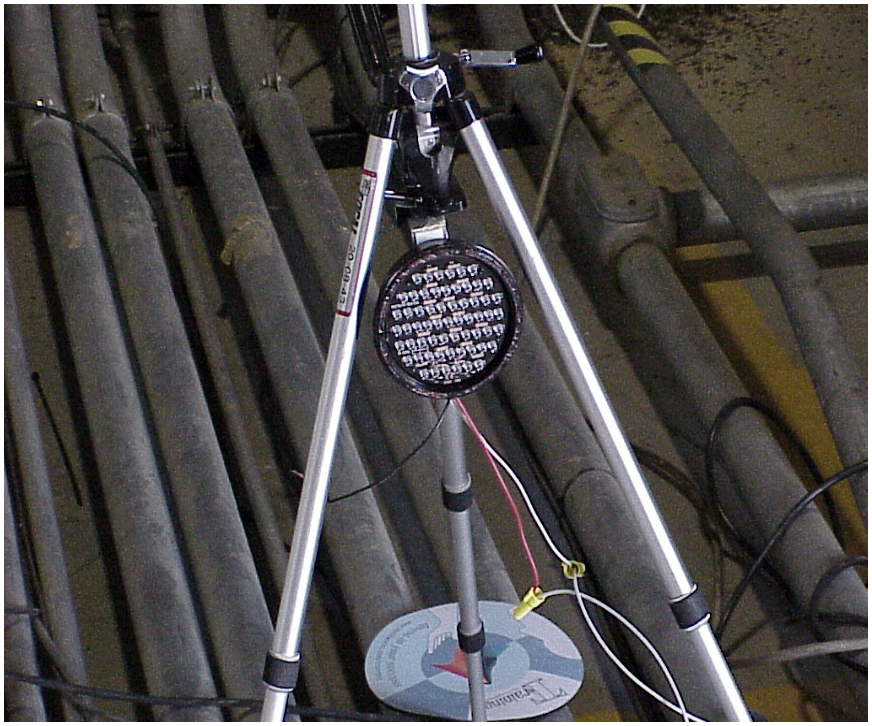
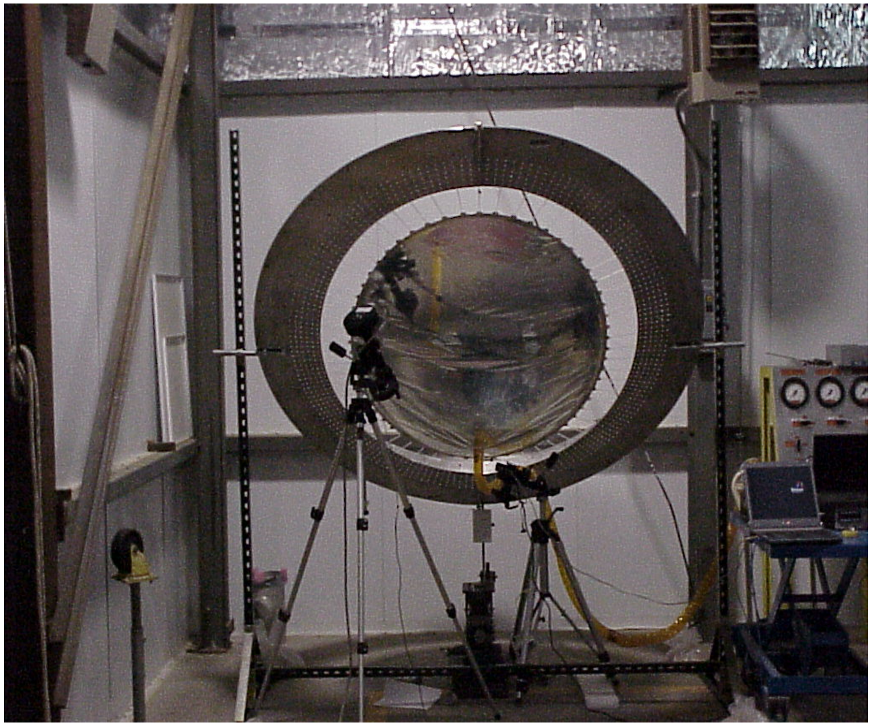
Experiment Setup Continued



Divergent Source



Concentrator From Source End

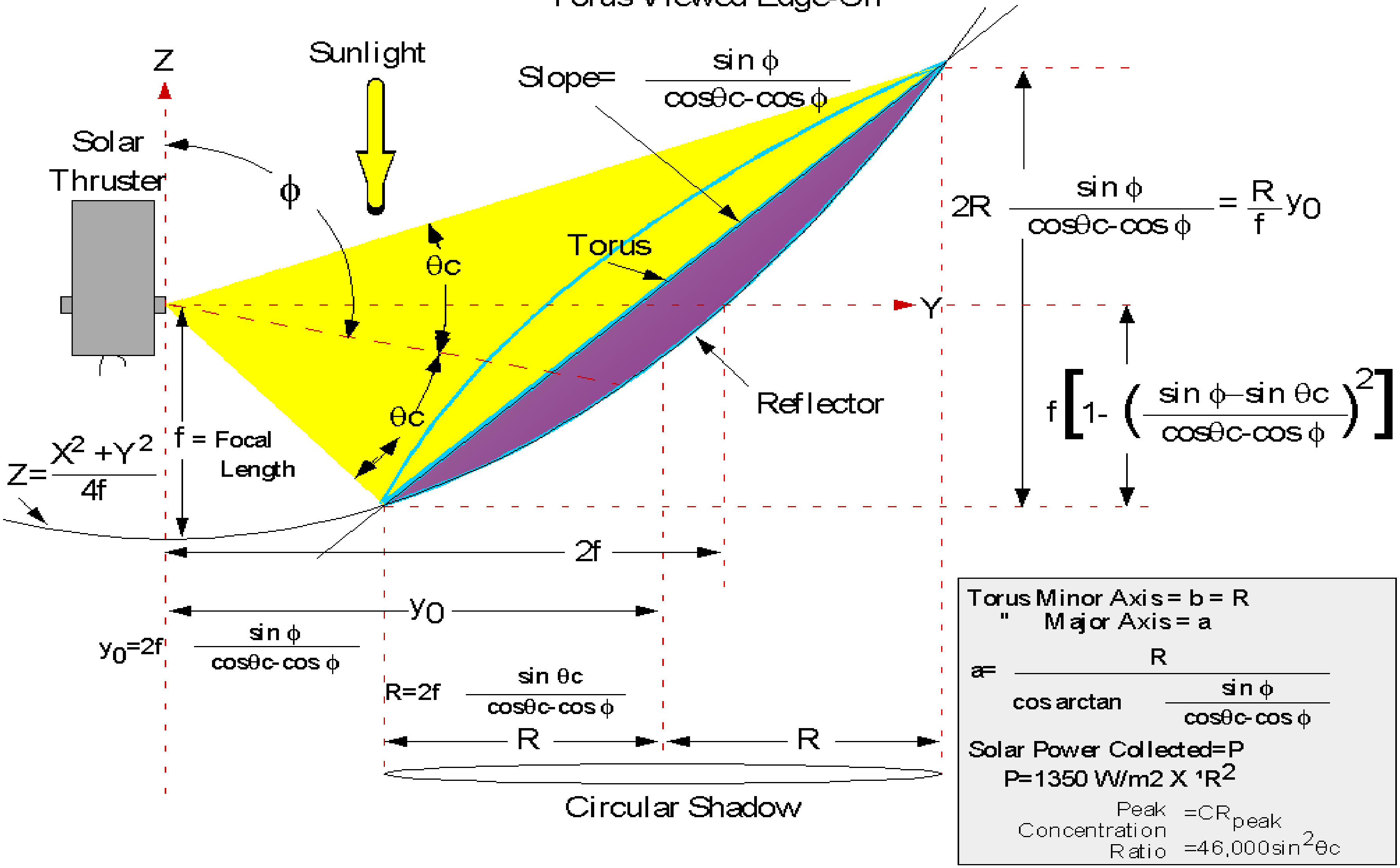
Conclusion and Future Work

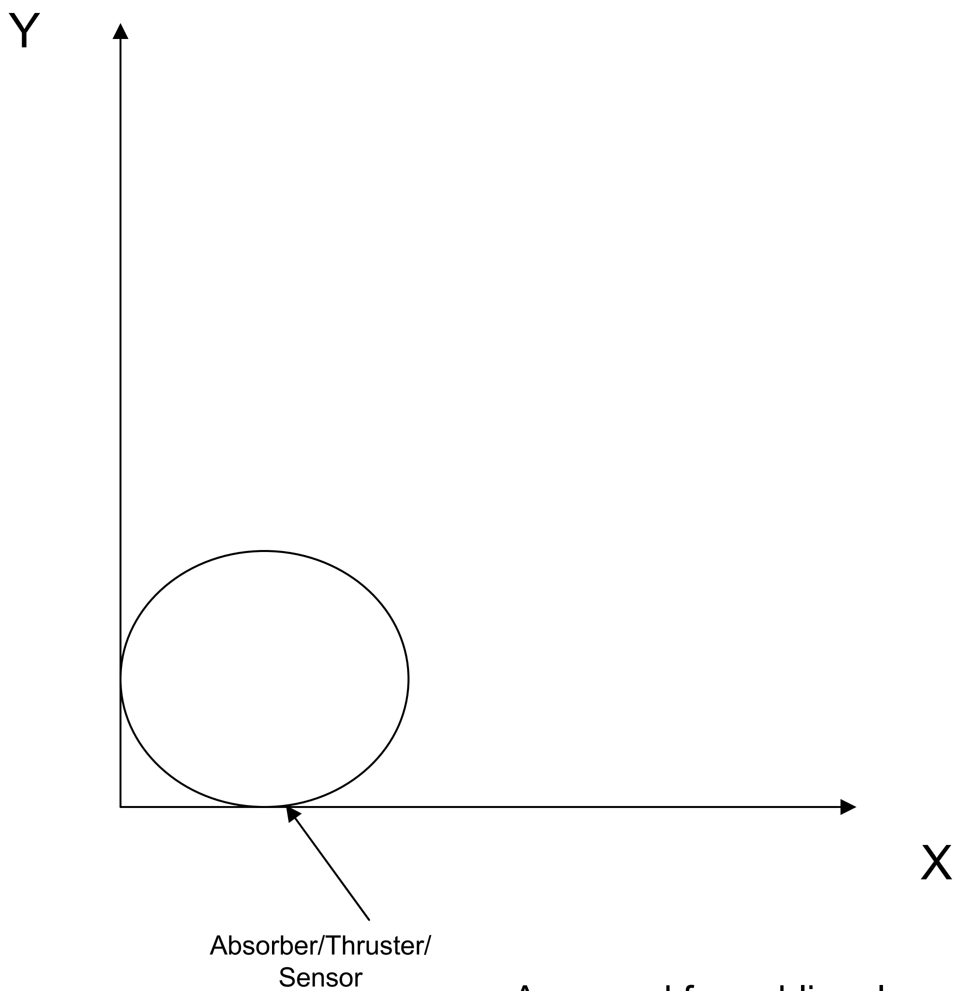
- Showed that the concept works with either method.
- Method 1: Correlation worked to about 1-2 diameters of misalignment.
- Method 2: Area moments worked well below 1 diameter. Removing center plate reflection helped as the focal spot moved below 1 diameter misalignment.
- Check out using the Phase Only Correlation (POC) to improve correlation.
- Automate the functions and apply to hexapod and concentrator.

BACKUP SLIDES

Geometry For Spacecraft

Solar Thruster Concentrator;
Torus Viewed Edge-On





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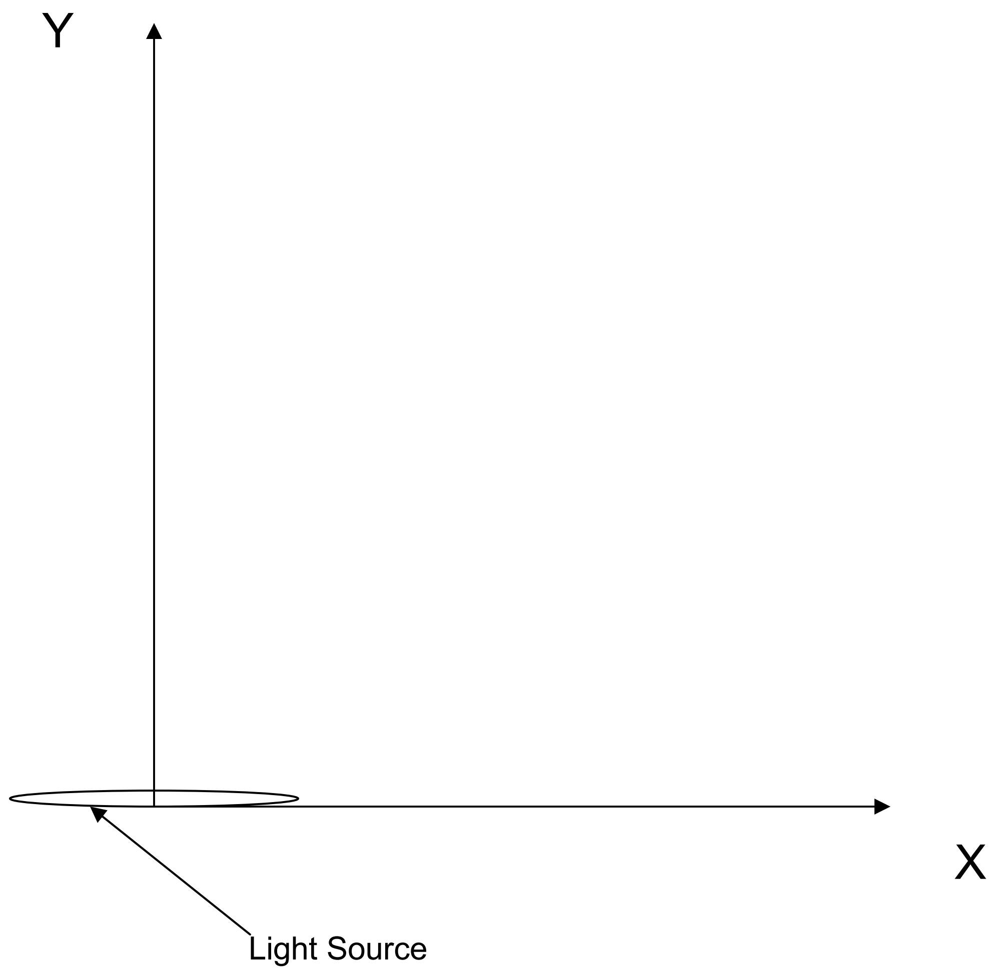

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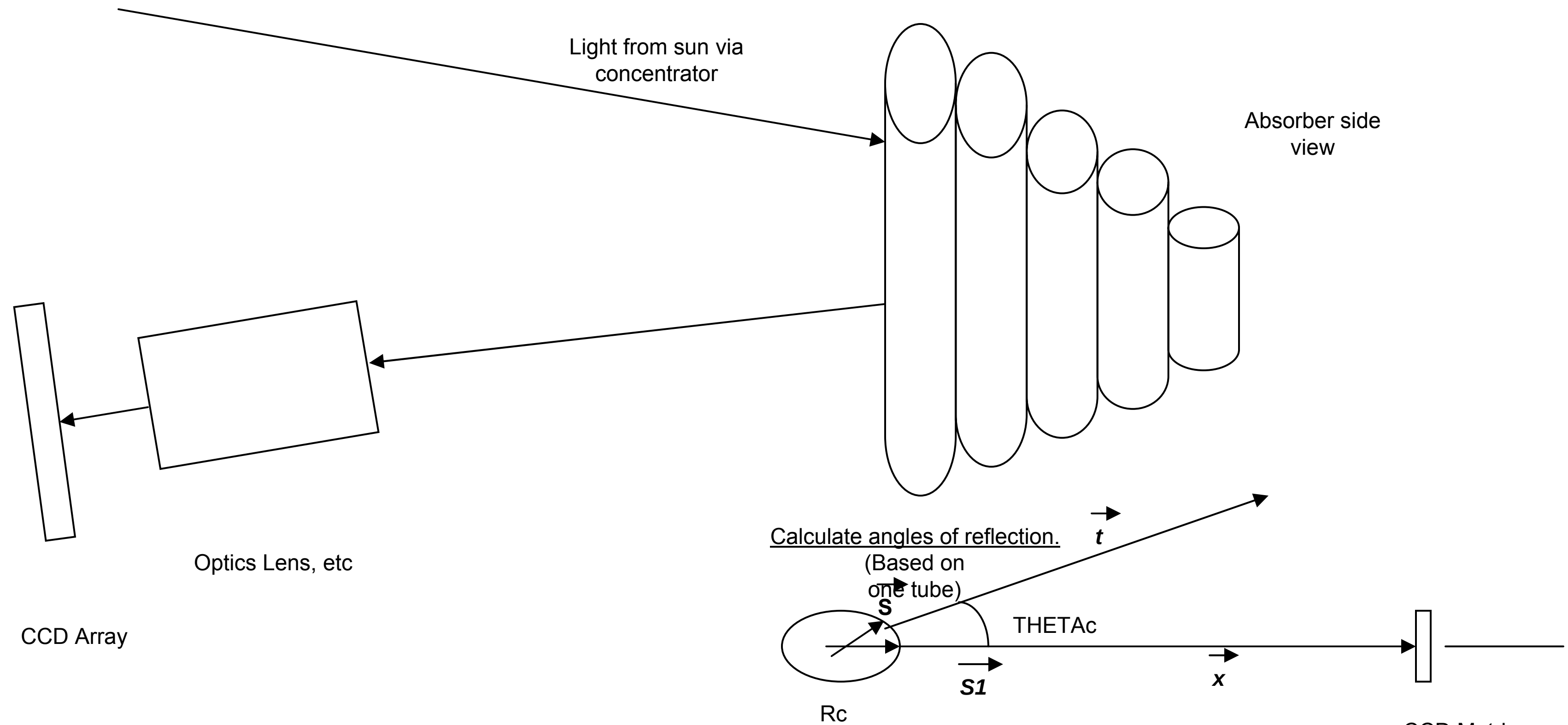
Focus Parameters

- The focal beam of a real concentrator is a distorted and spread Gaussian; since a non-imaging concentrator can have large aberrations and non-zero slope errors, the focal beam would not perform ideally.
- Maximum intensity is related to maximum temperature. However, this parameter is not enough to indicate when the focal maximum is above or below the absorber instead of having its focal maximum exactly on the absorber plane.
- The intensity on the absorber should be approximately symmetric for an on focus condition and may be utilized for coarse positioning as the focal beam is coming onto the absorber.
- Output temperature of the propellant could also be used as a determinant for on focus condition.
- Control to 0.1 inch and 0.1 degree are the required control tolerances.

Schematic of Proposed Solution



(vector equations)
x = (S1 – Rc*r)
t = (S-Rc*r)

FOV Calculate

Lens: f = 100 mm

Pixel in camera : 7.4 um

Distance from lens to absorber: 1 m

One pixel then covers:
(1000/100)*7.4um = 0.074 mm

So that the FOV is equal to:

H: 657 * 0.074 = 48.62 mm (2 inch)

V: 495 * 0.074 = 36.63 (1.4 inch)

THETAc is the angle we are trying to find.

X.r/|X| = t.r/|t|